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Effect of Maximum Size of Aggregate on Flexural Strength of Portland Cement Pavement Concrete

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16. ABSTRACT
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This report presents the results of tests conducted in 1952 in which the principal objective was the determination of the effect of flexural strength of reducing the maximum size of aggregate below 2-1/2 inches in a pavement slab 8 inches thick; and more specifically the effect of reducing the maximum size to 1-1/2 inches.

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STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS

EFFECT OF MAXIMUM SIZE OF AGGREGATE ON FLEXURAL STRENGTH OF PORTLAND CEMENT PAVEMENT CONCRETE

State of California
Department of Public Works
Division of Highways

MATERIALS AND RESEARCH DEPARTMENT
3435 Serra Way
Sacramento, California

March 5, 1957

Research No. 00268

Mr. J. W. Trask
Assistant State Highway Engineer
Division of Highways
Sacramento, California

Dear Sir:

Submitted for your consideration is a report of a laboratory investigation completed in 1952, on the subject of

EFFECT OF MAXIMUM SIZE OF AGGREGATE

ON

FLEXURAL STRENGTH OF PORTLAND CEMENT PAVEMENT CONCRETE

Study Made by . . . . Technical Section
Under general direction of. . . . . Bailey Tremper
Work Supervised by. . . . . L. P. Kovanda
Report Written by . . . . L. P. Kovanda and Bailey Tremper

Yours very truly

F. N. Hveem
Materials & Research Engineer

cc:M. Harris

EFFECT OF MAXIMUM SIZE OF AGGREGATE
ON FLEXURAL STRENGTH OF
PORTLAND CEMENT PAVEMENT CONCRETE

It is generally accepted that the strength of concrete having a given cement factor and slump becomes greater as the maximum size of aggregate is increased. This rule is based largely on results of compressive tests although Abrams(1)* found a similar trend in the flexural strength of concretes in which the maximum size of aggregate varied in six steps from No. 16 to 1-1/2 inches and which were tested in beams which were 10 inches wide by 7 inches deep and tested on a 36-inch span. The test specimens, therefore, were relatively large in relation to the size of aggregate. In pavement slabs having a thickness of the order of 8 inches, the improvement on beam strength by using large aggregate may well be questioned because of dimensional effects.

This report presents the results of tests conducted in 1952 in which the principal objective was the determination of the effect on flexural strength of reducing the maximum size of aggregate below 2-1/2 inches in a pavement slab 8 inches thick; and more specifically the effect of reducing the maximum size to 1-1/2 inches.

*See list of references at end of text.

SCOPE OF TESTS

Aggregates were prepared in three maximum sizes, namely, 2-1/2, 1-1/2 and 3/4 inches. Concrete aggregates manufactured from sand and gravel were obtained from two sources. These were Consolidated Rock Co.'s plant at Irwindale near Los Angeles and Perkins Gravel Co.'s plant at Perkins near Sacramento. Colton brand portland cement was used with the Irwindale aggregates and Calaveras brand portland cement with the Perkins aggregates. The aggregates were taken from existing stockpiles at the plants, approximately 8000 pounds were required from each source.

The principal test specimen was a beam 12 inches wide by 8 inches deep by 30 inches long which was loaded by the third-point method on a 24-inch span and with the finished side in tension. Auxiliary specimens consisted of 6"x6"x22" beams tested by the third-point method on an 18-inch span and 6"x12" cylinders for compressive strength tests. Aggregate larger than 1-1/2 inches was removed by screening the wet concrete before molding the cylinders and 6"x6" beam specimens from the 2-1/2 inch mixes. The static modulus of elasticity (secant 0-1000 psi) was determined by compression on the cylinder specimens.

All strength tests were made on moist cured specimens at the age of 28 days. In the case of the beams, curing during the first 48-hours was under wet cotton mats in the concrete fabrication room the temperature of which was not controlled. With this exception, all curing was in the fog room at 73°F.

Tests made on the fresh concrete included Kelly Ball penetration readings, standard slump test, air content by the pressure method, unit weight and Powers' remolding effort.

DATA OF THE TESTS

The test data are given in the following tables and figures:

Table I	Chemical and physical tests of the cements
Table II	Physical tests of the aggregates
Table III	Combined gradings of concrete aggregates
Table IV	Tests of fresh and hardened concretes
Table V	Air-entraining tests of the cements and fine aggregates
Table VI	Tests on concrete on Road IV-Ala-69-D,Hay,C Eastshore Freeway at Hayward
Figure 1	Relationship between water-cement ratio and compressive strength
Figure 2	Relationship between water-cement ratio and flexural strength

DISCUSSION

Workability

In an investigation involving variations in aggregates and aggregate gradation consideration must be given to workability, which is an important factor, before valid comparisons can be made between the effects on strength or other properties of the concrete. Data on which to predetermine suitable gradations for equal workability when the maximum size of aggregate is varied are not as extensive as desirable; however, the gradings of 2-1/2-inch and 1-1/2-inch aggregate used in this study were essentially the same as those determined experimentally to be satisfactory in placing concrete in the experimental paving project recently completed near Vacaville(2). On this project, the gradation of the 2-1/2-inch concrete was about that normally used and the gradation of the 1-1/2-inch concrete was a skip grading type which resulted in a concrete of satisfactory placeability, with only minor increases in water-cement ratio and percentage of fine aggregate as compared to the 2-1/2-inch concrete made with materials from the same sources. The gradation of the 3/4-inch maximum size of aggregate used in this study was estimated by judgment.

The water content of the experimental batches was regulated as closely as possible to maintain a slump of 2 inches. Close attention was paid to the amount of vibration required to properly mold the 8" x 12" x 30" beams in order to compare the workability of the different mixes.

The term "workability", as distinguished from slump, is used to describe that property of concrete that determines the ease with which it can be transported, placed, compacted and finished without undue segregation. Workability varies with the composition of the mix but the minimum workability required for a specific purpose depends on the effectiveness of the equipment to be used as well as the dimensions of the form to be filled and the presence or absence of obstructions such as reinforcement. Concrete that is sufficiently workable for one purpose may be too harsh under another set of circumstances. The measurement of workability is not simple and the interpretation of the results is complicated by the many factors pertaining to job conditions.

The best known laboratory instrument for measuring workability is the Powers remolding device which was used in this study. The device yields numerical values, known as "remolding effort" which are of some significance although the proper interpretation of the results to the problem at hand was not clear at the start. The method requires that aggregates coarser than 1-1/2 inches be removed from the sample before making the test. Uncertainties in comparing concretes containing different maximum sizes of aggregates are obvious. Nevertheless, it is felt that values of remolding effort, when considered in conjunction with the observed ease or difficulty with which test specimens could be molded, furnished a useful comparison of workability among the mixes being tested. Remolding effort is expressed as the number of jigs required to flatten a mass of concrete originally molded in a standard slump cone, while free flow is restricted by an annular baffle. A gage reading of 0 is reached when the concrete is at equal height on both sides of the baffle. A gage reading of 10 corresponds to the original 12-inch height of the molded specimen. Remolding effort values were recorded for gage readings of 2, 1 and 0 respectively for each batch of concrete tested and are shown in Table IV.

Observations of each batch mixed and a study of the remolding tests results led to the conclusion that all mixes were of comparable workability except those containing the 1-1/2-inch Irwindale aggregate. On the first round, this batch contained 38 per cent passing No. 4 and was decidedly harsh. On the succeeding two rounds, the per cent of passing No. 4 was increased to 40 per cent without marked improvement.

It was noted that all batches of Calaveras-Perkins concrete contained considerably more air than comparable mixes of Colton-Irwindale materials, a result that will be commented upon later. This finding led to the decision to add sufficient air-entraining agent (1/2 oz. Darex per sack) to the 1-1/2-inch Irwindale concrete on the fourth round to yield an air content comparable to that of the Perkins concrete. This resulted in a marked improvement in the workability observed in placing and as indicated in the remolding test. On the fifth round, the percentage of passing No. 4 in the 1-1/2-inch Irwindale mix was reduced to 38 per cent and Darex at the rate of one fluid ounce per sack of cement was added which resulted in an air content of 5.8 per cent. The workability of this batch was comparable to that of Round 4 and to that of the Perkins concrete.

Mention was made in the preceding paragraph that the Calaveras-Perkins combinations consistently entrained more air than did the Colton-Irwindale mixtures. For convenience of reference, the average results are tabulated below.

Per Cent of Air in Concrete

Maximum Size	Calaveras-Perkins	Colton-Irwindale
2-1/2	3.1	1.6
1-1/2	3.5	1.6 (First 3 rounds)
3/4	4.8	2.2
1-1/2 (Added AEA)		4.0 (4th round)
1-1/2 (Added AEA)		5.8 (5th round)

Normally it would be expected that the high air content found in the Calaveras-Perkins concretes would be due to higher-than-normal air-entraining properties of the cement. The data given in Table V however, do not substantiate this. When tested with Ottawa sand in accordance with Federal Specifications SS-C-158b, the Colton cement mortar contained 7.2 per cent of air and the Calaveras cement mortar contained 8.6 per cent of air. When each cement was tested in a similar manner with the Perkins and Irwindale sand, the Calaveras cement was found to entrain about 2 per cent more air than did the Colton cement. These differences in the mortar tests would not be expected to correspond to a difference of more than a few tenths of one per cent of air in the concrete. If the Perkins aggregate as a whole was responsible in part for the entrainment of excess air, such a result is not normal to the pit because air contents were determined in a large number of mixes using this aggregate in the Long Time Study of Cement Performance in Concrete(3) without any indication of excess air. Regardless of the causes, the fact remains that all Calaveras-Perkins mixes contained appreciably more air than did the Colton-Irwindale combinations and the effect of the air must be given consideration in evaluating the results of these tests. Entrained air, as is well known, improves the workability of concrete to a marked degree. Since the entrainment of abnormal amounts of air is presumed to occur infrequently (unless purposely accomplished) it is believed that the tests and observations of concretes produced by the Colton-Irwindale combinations in this study are more representative of results to be expected in general. It is probable therefore, that the use of 1-1/2-inch maximum size aggregate will introduce a measurable degree of harshness, as compared to 2-1/2-inch maximum concrete.

The laboratory tests do not afford a basis on which to determine the degree of workability actually required in the construction of pavements. Mention was made above of the experimental pavement containing 1-1/2-inch aggregate at Vacaville. While workability was adequate on this project, neither the remolding effort nor the air content was determined.

Recently work has been underway on a paving project near Hayward(4) in which the aggregate was of 1-1/2-inch maximum size nominally, although actually nearer 2 inches. Advantage was taken of the opportunity to test the concrete as it was being placed. The data of these tests are shown in Table VI. It will be noted that the grading of the aggregate was similar to that used in the Colton-Irwindale combination of the laboratory tests; that it was being placed with an average slump of 1.6 inches and that the air content was about 1.0 percent. Remolding effort as measured by the Powers' device fluctuated considerably but average values were as follows:

Number of Jigs to Attain Gage Reading		
2	1	0
91	159	296

These results are essentially the same as obtained in the laboratory 1-1/2-inch mixes of Colton cement and Irwindale aggregate and they thus furnish a useful guide as to the significance of the remolding tests and observations made in the laboratory. Progress on this construction project was very good and was not handicapped in any way by the character of the mix. The appearance of the longitudinal contact joint (tongue and groove) was observed to be about normal with respect to evidence of segregation. In 1400 lineal feet, there were 17 areas 6 to 8 inches long, 5 areas 12 to 14 inches long and 1 area 3 feet long showing honeycomb. The equipment on this project was in first class condition and consisted of a Blaw-Knox concrete spreader equipped with a full width pan vibrator, a two screed power finishing machine with tamper bar, and a Johnson float.

It may be concluded therefore, that mixes containing 1-1/2-inch maximum size aggregate will tend to be harsher than when 2-1/2-inch aggregate is used but that they can be placed and finished satisfactorily, and without delay, when good equipment is used. Were 3/4-inch max. size aggregate to be considered for concrete pavement, it appears that the concrete would be fully as workable as that obtained with 2-1/2-inch maximum size aggregate.

Strength

For convenient reference, the flexural strength of the 8" x 12" x 30" beams is tabulated below in terms of the percentage of 2-1/2-inch maximum size of aggregate.

Relative Modulus of Rupture - 8x12x30-inch Beams

Maximum Size	Calaveras-Perkins	Colton-Irwindale
2-1/2	100	100
1-1/2	97	98 (First 3 rounds)
3/4"	84	95
1-1/2 (Added AEA)		85 (Round 4, 4.0% air)
1-1/2 (Added AEA)		80 (Round 5, 5.8% air)

In these tests, disregarding workability, it may be concluded that a reduction in maximum size of aggregate from 2-1/2 inches to 1-1/2 inches does not significantly reduce the flexural strength of paving concrete. If, however, the workability resulting from the reduction in size of aggregate should need improvement, it is probable that, in accomplishing it by means of entrained air, a loss of from 10 to 15 per cent in flexural strength would occur. The effect on flexural strength by improvement of workability by further increasing the ratio of fine to coarse aggregate was not investigated, but the results obtained with the 3/4-inch maximum size concrete would indicate that the reduction in flexural strength may not be excessive.

As the maximum size of aggregate was reduced, the water requirement for equal slump increased. As would be expected, increases in water requirement were accompanied by decreases in strength. In Figure 1 the water-cement ratio-strength relationships of these tests are plotted. Curves derived by Abrams(1) and others are shown for reference. The figure indicates that both compressive and flexural strengths give curves that are parallel to the aforementioned curves. All results appear to be fairly well in accordance with the water-cement ratio except that results for 3/4-inch Colton-Irwindale concrete in 8" x 12" x 30" beams appear to be high by about 15 per cent.

If Abrams' data(1) are extrapolated to a maximum size of 2-1/2 inches, the indicated increase in strength over a maximum size of 1-1/2 inches does not exceed 5 per cent and thus they tend to confirm the results of the present tests.

In addition to the 8" x 12" x 30" beams, 6" x 6" x 22" beams and 6" x 12" cylinders were molded from each batch. When the concrete contained 2-1/2-inch aggregate, the particles larger than 1-1/2 inches were removed from the concrete by sieving before molding the latter two specimens. The data of these tests are summarized below on the basis of relative strengths:

Relative Flexural Strength - 6x6x22-inch Beams

Maximum Size	Calaveras-Perkins	Colton-Irwindale
2-1/2"	100	100
1-1/2"	102	95 (First 3 rounds)
3/4"	88	90
1-1/2" (Added AEA)		85 (Round 4, 4.0% air)
1-1/2" (Added AEA)		68 (Round 5, 5.8% air)

Relative Compressive Strength - 6x12 inch-Cylinders

Maximum Size	Calaveras-Perkins	Colton-Irwindale
2-1/2"	100	100
1-1/2"	86	88 (First 3 rounds)
3/4"	72	71
1-1/2" (Added AEA)		77 (Round 4, 4.0% air)
1-1/2" (Added AEA)		67 (Round 5, 5.8% air)

These data show that the indicated effect on flexural strength of reducing the maximum size of aggregate when tested in the smaller beams is similar to that obtained in the larger 8" x 12" x 30" specimens. The compressive strength however, is shown to be reduced more severly as the size of the aggregate is decreased.

Since it is the practice in the Division of Highways to make 6" x 6" beams as a control test during concrete pavement construction, it is of interest to compare the strength values with those of the larger beams. The data are summarized below:

Ratio of Flexural Strengths
6x6x22-inch beams to 8x12x30-inch beams

Maximum Size	Calaveras-Perkins	Colton-Irwindale
2-1/2"	1.05	1.16
1-1/2"	1.10	1.13
3/4"	1.10	1.10

The data shows that the test strength of the smaller beams is about 10 percent greater than that of the larger specimens. This is in line with the general law of dimensional effects in testing. The coefficient of variation between specimens of a group is an indication of the uniformity of the concrete. The results are summarized below for convenient reference.

Coefficient of Variation
8x12x30-inch Beams

Maximum Size	Calaveras-Perkins	Colton-Irwindale
2-1/2"	6.1	6.8
1-1/2"	5.5	5.4
3/4"	6.9	1.0

The data show greater uniformity among specimens containing 1-1/2-inch aggregate than 2-1/2-inch. This indicates that greater uniformity should result in pavement slabs containing the 1-1/2-inch aggregate, with fewer weak points at which cracks are apt to start.

CONCLUSIONS

The use of 1-1/2-inch maximum size aggregate in lieu of 2-1/2 -inch maximum size tends to lower the workability of 5-sack portland cement concrete. If the lowered workability is accepted the flexural strength of pavement slabs is not reduced seriously.

Observation and tests of full scale pavement construction employing 1-1/2-inch maximum size aggregate indicate that the reduced workability need not delay progress or prevent satisfactory placing and finishing of the concrete.

The combined grading of 3/4-inch maximum size aggregate as used in this study resulted in an appreciable loss in strength compared to that obtained with 2-1/2-inch aggregate. The experimental mixes however, were highly workable. The effect of redesigning the mix to give less workable and possibly higher strength was not investigated.

As a by-product of this study, it was discovered that one cement-aggregate combination resulted in the entrainment of abnormal amounts of air. This finding suggests the desirability of including tests for air as a routine procedure in all work to provide information that may assist in explaining the apparently anomalous results that are obtained from time to time.

LIST OF REFERENCES

1. "The Flexural Strength of Plain Concrete" by Duff A. Abrams, Proceedings, American Concrete Institute, Vol. XVIII (1922)

2. X-Sol-7-C,Vac,D, Experimental pavement near Vacaville, Research Nos. 00214 and 00263

3. "Long-Time Study of Cement Performance in Concrete" Chapter 5, Research Laboratories of the Portland Cement Association, Bulletin 30 (1949)

4. IV-Ala-69-D,Hay,C, Eastshore Freeway near San Lorenzo

TABLE I

Chemical and Physical Tests of the Cements

Brand	Calaveras	Colton
Oxide Analysis:		
SiO_2	24.9	22.9
Al_2O_3	3.8	4.4
Fe_2O_3	2.7	2.9
CaO	64.6	62.7
MgO	1.4	3.7
SO_3	1.2	1.7
Ignition Loss	0.7	1.0
Insoluble	0.21	0.09
Alkali (Na_2O = Na_2O+.658 K_2O)	0.48	0.60
Compound Composition:		
C_4AF	8	9
C_3A	6	7
$CaSO_4$	2	3
C_3S	44	43
C_2S	38	33
Specific Surface (Wagner)	1792	1728
Compressive Strength (A.S.T.M.)		
3 days (psi)	2345	2475
7 days (psi)	2444	2482
Normal Consistency (% Water)	24	26
Setting Time:		
Initial Set	4:40	4:20
Final Set	5:40	5:50
Autoclave Expansion (%)	+.010	+.089

TABLE II

PHYSICAL PROPERTIES OF THE AGGREGATES

	Perkins Gravel Co. Perkins, Calif.	Consolidated Rock Company Irwindale, Calif.
Bulk Sp.G (SSD)		
Sand	2.70	2.58
1" x No. 4	2.77	2.62
1-1/2" x 1"	2.77	2.71
2-1/2" x 1-1/2"	2.78	2.67
Absorption, %		
Sand	2.0	1.4
1" x No. 4	0.8	1.0
1-1/2" x 1"	0.3	0.5
2-1/2" x 1-1/2"	0.3	0.2
Loss in Soundness Test, %		
Sand	3.2	1.6
1" x No. 4	0.7	1.1
1-1/2" x 1"	0.5	0.5
2-1/2" x 1-1/2"		0.2
Organic Matter in Sand, Plate No.	1	1
Mortar Strength of Sand, % Ottawa		
7 days	104	111
28 days	113	115

TABLE III

Combined Gradings of Aggregates
in per cent passing

Maximum Size of Aggregate	2-1/2"		1-1/2"		3/4"	
Source of Aggregate	Perkins	Irwindale	Perkins	Irwindale	Perkins	Irwindale
Sieve Size:						
3"	100	100				
2-1/2"	99	99				
2"	91	91	100	100		
1-1/2"	73	73	97	97		
1"	51	51	57	57	100	100
3/4"	45	45	48	48	90	90
3/8"	40.5	41	43	43	54	54
No. 4	36	36	38	40	47	47
No. 8	32	32	34	35	42	41
No. 16	26	26.5	27.5	29	34	35
No. 30	16.5	18.5	17	20	21.6	24
No. 50	5.7	7.0	6	7.7	7.4	9
No. 100	1.6	1.8	1.7	2.0	2.1	2.4
No. 200	0.8	1.1	.9	1.2	1.0	1.4
Unit Weight, Dry, rodded lbs. per cu. ft.	105.2	101.1	103.5	99.9	104.1	99.5
Voids in coarse aggr., per cent	39.4	39.6	40.1	40.6	39.8	39.1

Note: These are combined gradings for the last four (4) rounds and except for the fifth (5) batch of the Irwindale-Colton 1-1/2-inch mix.

TABLE IV

TESTS OF FRESH AND HARDENED CONCRETE

Source of Aggregate	Cement	Maximum Size of Aggregate	Fine Aggr. % Pass. No. 4	Water Pounds Per Sk.	Consistency Kelly Inches	Consistency Slump Inches	Air %	Wet Concrete Wt. per Cu. Ft.	Cement Factor Sacks per Cu. Yd. (Set)	Admixture (Darex) Oz. per Sk.	Powers Remolding Effort Gate Reading 2	1	0	BEAMS 6" x 6" x 22" Weight per Cu.Ft. Set	Modulus of Rupture PSI	BEAMS 8" x 12" x 30" Weight per Cu.Ft. Set	Modulus of Rupture PSI	CYLINDERS 6" x 12" Weight per Cu.Ft. Set	Compr. Strength PSI	Modulus of Elasticity at 1000 PSI x 10^{-6}
Perkins	Calaveras	2-1/2"	35.5	40.9	1	1-7/8	3.1	154.5	5.01	None	26	36	58	147.6	553	154.2	558	150.2	4335	5.5
"	"	"	36.0	42.5	3/4	1-7/8	2.8	150.9	5.05	"	24	32	52	148.5	636	154.7	563	150.4	4255	5.4
"	"	"	36.0	44.2	3/4	1-1/2	3.4	152.8	4.96	"	24	32	47	147.2	653	152.4	621	149.2	4250	5.0
"	"	"	36.0	44.2	1	2-1/4	3.3	151.3	5.02	"	22	31	51	151.1	609	154.5	600	149.3	4420	5.4
"	"	"	36.0	45.0	1	2-1/2	3.1	151.7	5.06	"	18	27	46	147.8	564	155.6	520	149.0	3850	4.5
Average		2-1/2"	35.9	43.4	0.9	2.0	3.1	152.2	5.02	None	22.8	31.6	50.8	148.4	603	154.3	572	149.6	4222	5.16
Perkins	Calaveras	1-1/2"	37.5	47.5	1-3/8	3	3.5	151.7	4.97	None	34	56	88	152.2	616	152.6	578	153.8	3410	5.5
"	"	"	38.0	45.0	1-1/8	2	3.6	149.7	5.03	"	32	48	78	152.9	580	152.9	533	151.6	3490	5.2
"	"	"	38.0	45.9	1-3/8	2-3/4	3.3	151.3	5.01	"	49	89	138	152.4	678	153.0	605	153.1	3670	5.1
"	"	"	38.0	45.0	1	2	3.5	151.7	5.02	"	35	54	88	155.4	619	152.9	523	151.3	3985	5.1
"	"	"	38.0	45.9	7/8	1-5/8	3.8	150.9	5.03	"	42	73	106	154.1	582	153.3	541	151.7	3670	5.0
Average		1-1/2"	37.9	45.9	1.15	2.27	3.5	151.1	5.01	None	38.4	64.0	99.6	153.4	615	152.9	556	152.3	3645	5.18
Perkins	Calaveras	3/4"	48.5	56.7	1-3/8	2-1/2	4.8	146.1	4.79	None	19	28	43	145.7	464	145.7	508	147.2	2850	4.2
"	"	"	47.0	53.4	1-1/8	3-1/4	4.9	145.7	4.85	"	19	28	43	145.7	502	146.1	480	148.6	3155	4.3
"	"	"	47.0	54.2	1-3/8	2-1/2	4.2	146.8	4.97	"	15	22	37	149.2	528	149.4	523	147.8	3020	4.3
"	"	"	47.0	53.4	1-3/8	2-1/2	5.0	145.7	4.86	"	20	29	45	149.7	586	146.4	463	147.8	3080	4.4
"	"	"	47.0	54.2	1-1/2	2-1/2	5.0	146.1	4.88	"	17	24	40	148.5	567	146.9	429	146.8	3000	4.3
Average		3/4"	47.3	54.4	1.35	2.65	4.8	146.1	4.87	None	18.0	26.2	41.6	147.8	529	146.9	481	147.6	3021	4.30
Irwindale	Colton	2-1/2"	36.0	44.2	1	1-3/4	1.8	153.7	5.07	None	25	35	57	147.8	668	151.9	576	150.1	4415	3.9
"	"	"	36.0	45.0	1	2-3/8	1.2	152.5	5.04	"	21	33	54	150.5	617	152.0	514	149.5	4310	4.0
"	"	"	36.0	45.0	1	2-1/2	1.7	151.7	5.14	"	15	24	45	147.1	648	154.6	597	149.1	4330	3.8
"	"	"	36.0	45.0	1	2-1/2	1.4	152.9	5.11	"	15	24	44	150.7	621	153.7	499	148.6	3965	3.8
"	"	"	36.0	45.0	1	3	2.1	152.1	5.05	"	28	44	79	149.1	598	152.2	534	148.0	4055	3.7
Average		2-1/2"	36.0	44.8	1.0	2.42	1.6	152.6	5.08	None	20.8	32.0	55.8	149.0	630	152.9	544	149.1	4215	3.84
Irwindale	Colton	1-1/2"	38.0	45.9	7/8	2-1/8	1.8	152.1	5.19	None	112	178	314	152.7	565	155.3	544	152.1	4025	3.6
"	"	"	40.0	47.5	7/8	2	1.6	150.9	5.07	"	86	125	253	152.7	650	152.6	490	152.2	3670	3.7
"	"	"	40.0	49.2	1	2-3/8	1.4	150.9	5.01	"	78	150	254	155.8	586	150.8	556	152.7	3470	3.4
Average		1-1/2"	39.3	47.5	0.92	2.17	1.6	151.3	5.09	None	92.0	151.0	273.7	153.7	600	152.9	530	152.3	3722	3.57
Irwindale	Colton	1-1/2"	40.0	47.5	7/8	2-5/8	4.0	147.7	4.96	0.5	38	66	138	149.1	563	149.3	463	148.5	3250	3.4
"	"	"	38.0	45.0	1-1/4	2-3/4	5.8	144.0	5.04	1.0	34	56	106	148.1	430	148.3	435	145.4	2840	3.1
Irwindale	"	3/4"	49.0	56.7	1-1/8	2	2.1	148.5	5.04	None	20	31	51	148.5	462	147.2	511	149.3	3020	3.4
"	"	"	47.0	55.0	1	2	2.1	148.1	4.96	"	32	47	79	151.1	570	147.1	512	149.5	3020	3.5
"	"	"	47.0	55.9	1-1/2	2-1/2	2.2	147.3	5.02	"	27	40	66	152.2	623	149.0	518	148.6	2885	3.2
"	"	"	47.0	55.0	1-1/8	2-1/8	2.1	147.3	4.99	"	31	47	75	151.3	571	148.2	508	148.8	3115	3.4
"	"	"	47.0	55.9	1-1/2	2-1/2	2.6	147.7	5.03	"	21	30	51	149.3	593	149.4	523	148.8	2860	3.6
Average		3/4"	47.4	55.7	1.25	2.22	2.2	147.8	5.01	None	26.2	39.0	64.4	150.5	564	148.2	514	149.0	2980	3.42

Note: All strength tests are at age of 28 days and have been adjusted for cement content of 5.0 sacks per cubic yard

TABLE V

Air-Entraining Tests of the Cements and Fine Aggregates

Cement	Sand	Percent Air
Colton	Ottawa	7.2
Calaveras	Ottawa	8.6
Colton	Irwindale	4.8 4.9 4.8
Colton	Perkins	5.0 5.1 5.0
Calaveras	Irwindale	6.4 8.1 7.2
Calaveras	Perkins	7.2 6.9 7.0

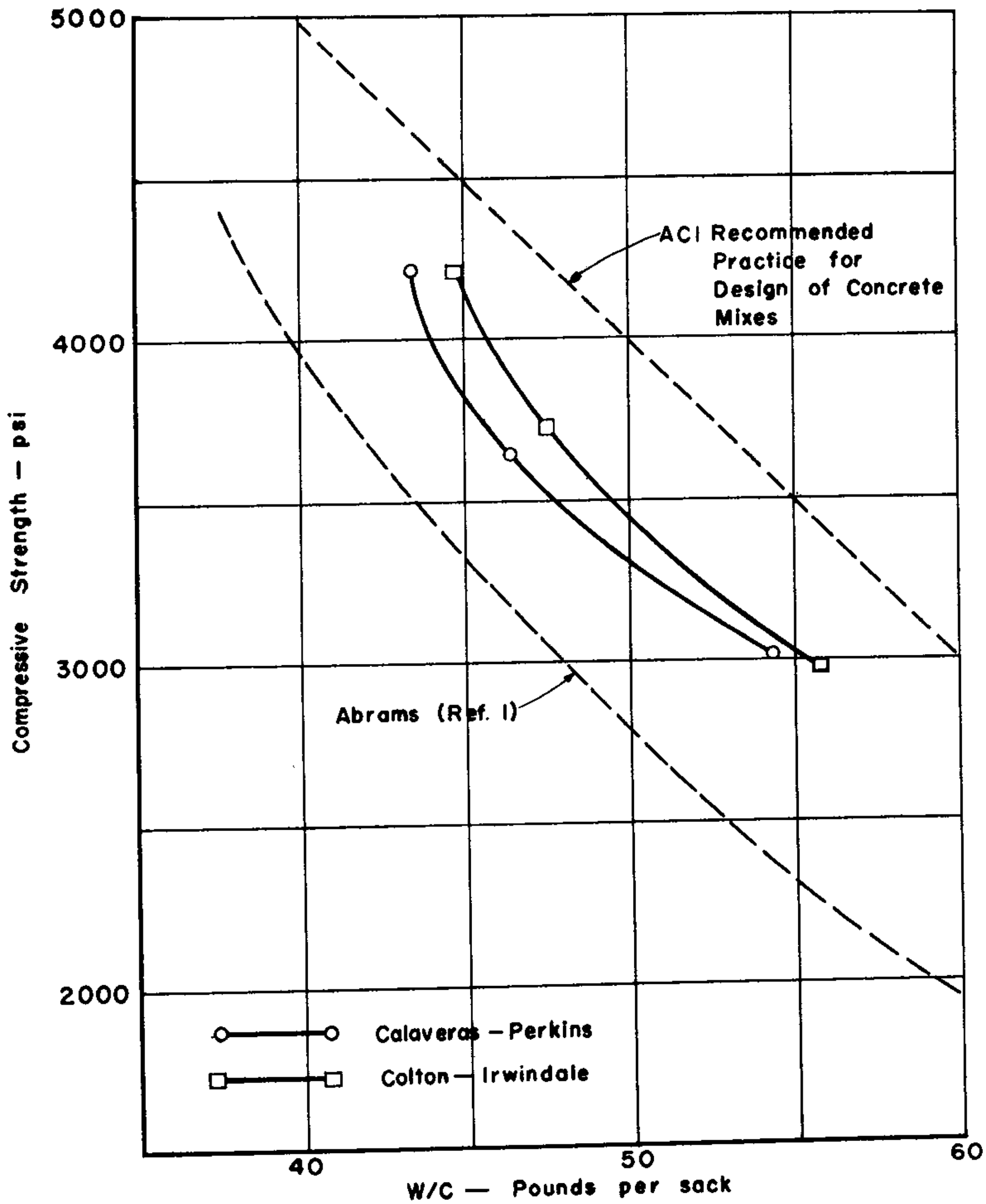
TABLE VI

Concrete Test Data of 1-1/2-inch Paving
Concrete Placed in Right Outer Lane
of Road IV-Ala-69-D,Hay.C on
Contract 52-4TC19-F on
November 5 & 6, 1952

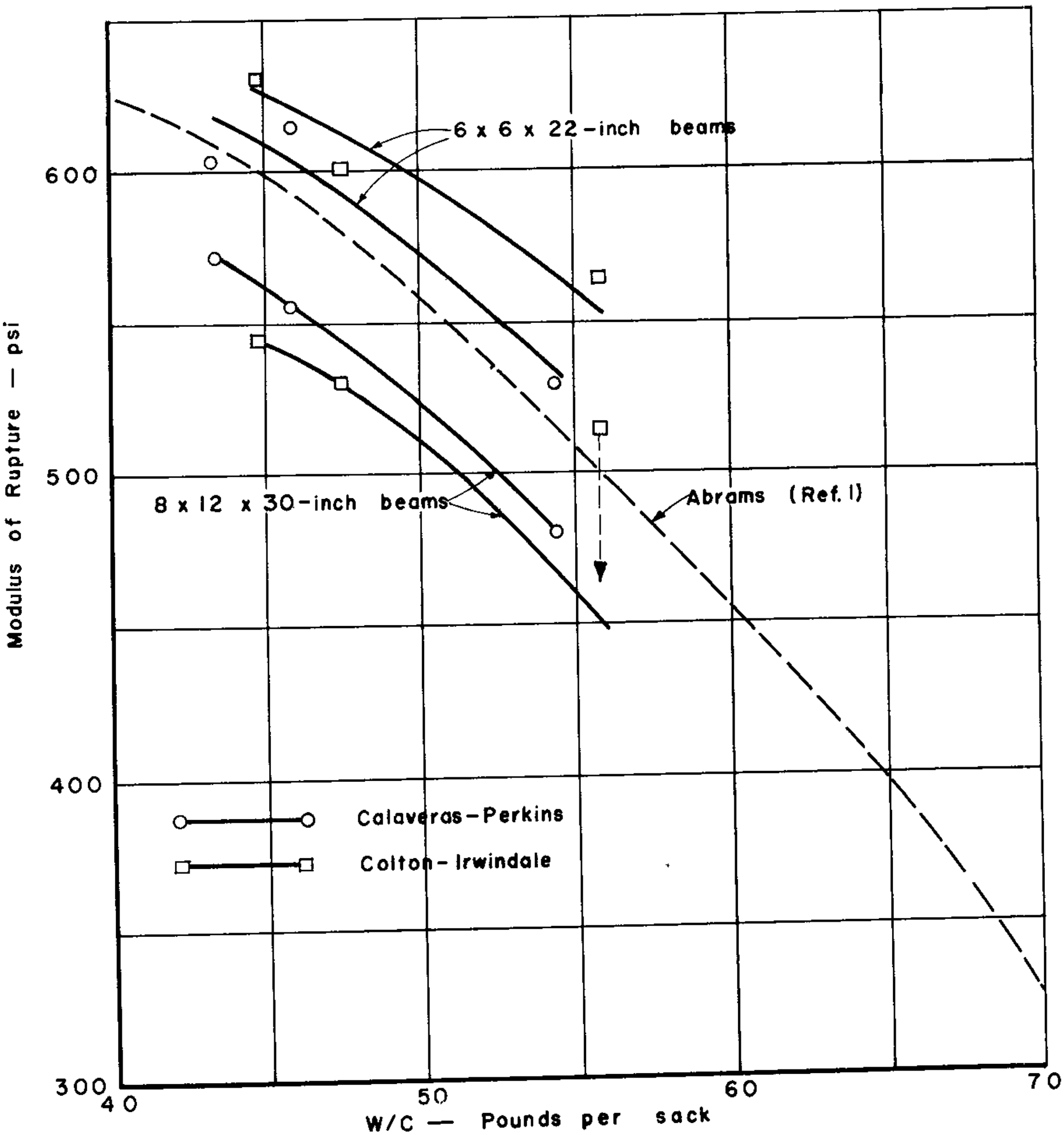
Station	Consistency		%	Remolding Effort Gage Readings		
	Kelly	Slump	Air	2	1	0
133+00	3/4"	1-5/8"	1.0	119	225	420
129+00	1-1/4	2-1/2	0.9	45	90	177
124+00	5/8	1-1/2	1.0	107	165	350
120+50	7/8	1-3/4	1.0	71	125	255
112+00	3/4	1-1/2	1.1	69	116	207
109+50	7/8	1-1/4	---	124	206	383
106+00	3/4	1-3/8	---	90	160	272
103+00	5/8	1-3/8	---	103	185	308
Average	.81"	1.61"	1.0	91	159	296

Combined Gradings of Aggregates on
November 5, 1952

Sieve Size	Percent Passing
2"	100
1-1/2"	90
1"	63
3/4"	52
3/8"	48
No. 4	40
No. 8	34
No. 16	22
No. 30	15
No. 50	7
No. 100	3
No. 200	2



RELATIONSHIP BETWEEN WATER-CEMENT RATIO AND COMPRESSIVE STRENGTH



RELATIONSHIP BETWEEN WATER — CEMENT RATIO AND FLEXURAL STRENGTH